Conseil Consultatif pour les Eaux Occidentales Septentrionales
North Western Waters Advisory Council
Consejo Consultivo para las Aguas Noroccidentales

NWWAC webinar on climate change impacts on cod in the Celtic Sea

12 June 2024

REPORT

Welcome & introductions - Moderator: Jean-Marie Robert, WG2 Vice chair

The Moderator welcomed all participants and thanked the Secretariat for organising the webinar as well as the interpretation team for their support.

He outlined that the management of cod in the Celtic Sea was not a new issue and has been addressed by the North Western Waters Advisory Council (NWWAC) over many years. However, he commented that a new dimension is now in play with the 0 catch advice introduced. Catch advice for other species have also been lowered with a view to preserving cod stocks. Fisheries operating in the Celtic Sea are observing a deterioration of the situation with further depletion of cod stocks. The question is how to manage the stocks and the fleets operating in the area. "*We are at a crossroads between the status of the stock, scientific advice, management measures and the economic operations of the fleets.*" The AC has tried before to frame this, but members feel that up-to-date information on climate change is missing. We do know that, due to climate change, the Celtic Sea is no longer appropriately adapted to the life cycle of cod due to warming waters.

He felt that the presentations included on today's' agenda would provide a basis for an open discussion.

Celtic Sea cod: ICES, assessment, advice and a thimble of literature - Jonathan White, Marine Institute

Jonathan White, Marine Institute Ireland, is Chair of the ICES WG for the Celtic Sea region as well as the ICES Fisheries Resources Steering Group. He provided a brief introduction of the ICES advice in 2023 for cod stating "*when the MSY approach and precautionary considerations are applied, there should be zero catch in 2024*" before giving insight into ICES approach to fisheries stock assessment and the process of advice production.

He presented results from WKCELTIC which updated various aspects of the assessment and the model being used (SAM). While landings have gone down overall, recruitment and SSB have also reduced with fishing pressure increasing. Both catch and SSB heavily rely on the 2023, 2022 and 2024 age classes in the forecast 2024 catch, and 2025 Spawning Stock Biomass.

White then pointed to the environmental drivers for the stock/recruitment relationship and felt that work has been carried out on this by scientists for decades.
For cod, stock recruitment points are used to define the reference points for the stock, i.e. at which point the fishing pressure needs to be reduced to not compromise the stock's biomass. Consideration is given to the MSY approach, precautionary approach and the management plan. Starting point is the lowest point where a good size recruitment can be observed (2006).

He explained that biotic factors, e.g. predation, food availability, growth etc., and abiotic factors, e.g. temperature regimes, current, pH etc., can be assumed to influence stock status, however, proving robust linkages to each biotic or abiotic factor is not easy. While oceanographic modelling can provide a lot of this information, fishing data points related to these are limited (note one stock-recruitment point representing a year for the entire stock). "*The majority of stock assessments do not explicitly incorporate environmental drivers of any form"* as it is too complex to associate the biotic and abiotic factors to stock recruitment factors, though stock-recruitment relationships implicitly incorporate all biotic and abiotic factors, linking the recruitment that has resulted from the spawning stock.

White presented a brief overview of research currently being carried out on cod:

- Righton et al., (2010). Thermal niche of Atlantic cod *Gadus morhua*: limits, tolerance and optima. MARINE ECOLOGY PROGRESS SERIES. Vol. 420: 1–13, 2010. doi: 10.3354/meps08889; https://www.int-res.com/articles/suppl/m420p001_supp.pdf

- Möllmann, C., Cormon, X., Funk, S. et al. (2021) Tipping point realized in cod fishery. Sci Rep 11, 14259 Möllmann, C., Cormon, X., Funk, S. et al. (2021) Tipping point realized in cod fishery.

- Wright, Pinnegar and Fox (2020) Impacts of climate change on fish, relevant to the coastal and marine environment around the UK. MCCIP Science Review 2020, 354–381. https://www.mccip.org.uk/sites/default/files/2021-07/16_fish_2020.pdf

- Winter, A.-M., Richter, A., and Eikeset, A. M. (2020). Implications of Allee effects for fisheries management in a changing climate: evidence from Atlantic cod. Ecol. Appl., 30, e01994, https://www.jstor.org/stable/26870854

- Winter, A.-M., Vasilyeva, N., and Vladimirov, A. (2023) Spawner weight and ocean temperature drive Allee effect dynamics in Atlantic cod, *Gadus morhua*: inherent and emergent density regulation, Biogeosciences, 20, 3683–3716, https://doi.org/10.5194/bg-20-3683-2023

- Ellis, et al., 2024. Variable trends in the distribution of Atlantic cod (*Gadus morhua*) in the Celtic seas. Journal of Fish Biology. https://onlinelibrary.wiley.com/doi/10.1111/jfb.15715

- Lundy et al, 2022. Tagging study to determine mortality sources on cod in the Irish Sea; European Maritime and Fisheries Fund (EMFF). https://op.europa.eu/en/publication-detail/-/publication/c8a63ce2-1f6c-11ed-8fa0-01aa75ed71a1

- ICES (2023). Cod (Gadus morhua) in Division 7.a (Irish Sea). ICES Advice: Recurrent Advice. Report. https://doi.org/10.17895/ices.advice.21840786.v1

He concluded that the marine ecosystem is very complex with biological and environmental drivers, and the attempt to include socio-economic factors as well. He referred to the recent ICES WKCLIMAD stating that "*hard linkage of environment to recruitment and population growth remains the Holy Grail of fisheries science.*"

The Moderator thanked the speaker and commented that there are certain factors in recent publications that have not yet been taken into account by the AC in its advice development.

Franck Le Barzic thanked White for his insightful presentation. He felt that the biomass limit in 2006 was set in an environment which was very different from the current one and was wondering if the current reference points are still valid.

White explained that this depended on the perception of the stock, what the stock could or should be, and that reference points needed to be comparable and realistic. *"While the points may seem relatively high to what the stock is now as compared to in the past, they are not high, they are realistic to the stock status we have seen in the not too distant past."*

Cod in the Celtic Sea ecosystem: ecological niche and a few insights from food-web modeling - Pierre-Yves Hernvann, Ifremer

Pierre-Yves Hernvann explained that the work carried out was a few years old as part of his PhD studies. He explained that the Celtic Sea has a wide variety of environmental conditions favouring a large range of fish species. Crucial for European fisheries, this area is situated across a biogeographic boundary hosting both Boreal and Lusitanian species, which has implications on how the ecosystem may respond to climate change. He explained that there has been a long history of ecosystem modelling in the area, which gave birth before his PhD studies to a Celtic Sea Ecopath and Ecosim (EwE), i.e. a temporally dynamic mass balance food-web model. This model represents the ecosystem through an ensemble of functional groups, i.e. single species or groups of species sharing similar ecological characteristics. In this model, cod has its own functional group. However, at that stage, only fishing was included as a driver of ecosystem dynamics. Therefore, his PhD aimed at understanding the relative effects of environment and fishing on the Celtic Sea dynamics in the past, to then better predict the response of the ecosystem to future climate change. In particular, this work was accomplished by better representing the dynamics of low trophic levels (pelagic primary and secondary producers) and the response of higher trophic levels to environment, by explicating the response of their productivity to temperature, and the response of their spatial distribution to other multiple drivers.

Hernvann provided a brief overview of the environmental conditions in the Celtic Sea, focusing on environmental variables for which we expect substantial changes in the as a response to climate change according to biogeochemical models: both sea surface and sea bottom temperatures, are projected to increase everywhere in the Celtic Sea, but heterogeneously through space, and primary production, which is expected to decrease (with spatial heterogeneity, slight increases in some coastal areas but substantial decline offshore).

He explained that, to inform the response of high trophic level species to the environment, the concept of the environmental niche is used. In the EwE model, the niche assumes that the production and the consumption of the functional group will be optimal within a particular range of values for specific environmental variables. To do so, Hernvann designed and fitted a niche modelling framework to explain the probability of presence of fish by environmental variables pertinent with the ecology of the species, hence estimating the functional responses of the Celtic Sea species to these variables, and project the suitability of habitat for them.

In particular, the warming phase in the early part of the historical period may explain the decrease in the productivity of cod, which is in line with trends observed in the stock assessment (see the stock-recruitment relationship). The Ecospace model (i.e. spatial version of the food-web model) suggests that, in response to these environmental changes, the distribution of Boreal species, including cod, tends to contract, with higher proportion of the total biomass of Boreal species located in the cold pool area, South Ireland.

Hernvann finally showcased the future projections conducted with the food-web model. In these climate change simulations, the food-web model predicts that the decline in the primary production (informed from the biogeochemical models) will be trophically amplified in the food-web, leading to substantial decline in the biomass of high trophic levels. The model also predicts that this decline will be steeper for Boreal species than the Lusitanian species, suggesting a deborealisation of the Celtic Sea on the top of the overall decline in the ecosystem production.

Hernvann concluded with the following statements:

- As a result of the reduction in its environmental niche, cod will be one of the first/most commercial stocks negatively affected by climate change in the Celtic Sea
- Productivity and biomass will decrease
- Spatial distribution will contract
- Consequences of climate change on cod will worsen with time
- …and depend on the severity of climate change
- But keep in mind that environmental niche isn't everything!
- It is crucial to consider overall ecosystem changes and species interactions too
- What we want to do with fishing will matter

Presentation on the study "Latitudinally distinct stocks of Atlantic cod face fundamentally different biophysical challenges under on-going climate change - Svein Sundby, Institute of Marine Research, Norway

Svein Sundby explained that the issue of climate change is related to longer term processes than just the last 20-30 years referring to an ICES report from 1948 from a meeting on climate changes in the Arctic. This included a time series of temperature in the Barents Sea showing an increase starting in 1900. The ICES meeting concluded that fish species in the northern part of the North Atlantic were displaced northwards and the abundance in the northernmost region (including the Arctic) increased. The subsequent ocean temperature declined again into the early 1980s. Along with the temperature decline marine organisms were displace southward again and abundance of fish species in the Arctic, including the Barents Sea cod, declined. At that time the decline of the species in the Arctic was not linked to the decreasing temperature, but rather to overfishing. Further time series show the Atlantic Multidecadal Oscillation (AMO) is still in place, however, the predictability of AMO is low u compared to the component of anthropogenic global climate change.

Sundby provided insight into spawning migration of Northeast-Arctic cod which is a critical variable for this stock. Warming and cooling waters have a distinct impact on the spawning activity. In warming periods, spawning sites are displaced northwards and the spawning stock increases. In cooling phases, the spawning sites are displaced southwards and spawning stock size decreases.
Increasing temperature in the North Atlantic and the Barents Sea is also linked with an increase in the *Calanus finmarchicus* population. The opposite can be observed in the North Sea where the increase in temperature leads to a decrease in the flux of *Calanus*. Changes have been observed in the matching of the spring-spawning copepods with cod spawning with a general decrease identified since the 1990s.

Oppositely to the Barents Sea cod, North Sea cod biomass has declined since the 1960s "Gadoid outburst" but increased somewhat over the very recent years in line with the abundance of *Calanus finmarchicus*, but not as much between temperature and spawning stock biomass indicating that the abundance of cod is linked more strongly to *C. finmarchicus* rather than temperature. During the recent 30 years gadoids in the North Sea have moved to the northeast with new species moving in from the Channel such as sardines and hake.

In conclusion, abundance of Atlantic cod stocks in the northernmost habitats (e.g. Barents Sea cod) respond to climate change oppositely of the Atlantic cod stocks in the southernmost habitats (e.g. North Sea cod).

Sundby observed that 10 degrees Celsius is critical for the spawning of cod. When this is exceeded, spawning becomes erratic and becomes less successful. Currently, the southern part of the Celtic Sea is on the edge of this critical spawning temperature, but predictions show that in future only the northern part of the Irish Sea will be suitable for spawning.

He concluded that climate-induced decline/northward displacement of cod populations associated with the Celtic Seas are probably linked to multiple causes:

- Most importantly, in the southernmost part of the habitat, ambient temperature for maturing and spawning cod are at the limit of being supercritical resulting in unsuccessful spawning.
- In central to northern regions, change in suitable prey species (e.g. spring-spawning copepods like *Calanus finmarchicus*) may have contributed to reduced offspring survival.

He added that the mechanism that caused the decrease of cod in the central and northern regions of the North Sea can be related to the changes in spring-spawning copepod species.

Presentation on the study "Ocean warming shapes embryonic developmental prospects of the next generation in Atlantic cod?" - Kaja Skjærven, Institute of Marine Research, Norway

Kaja Skjaeven explained that the presentation is based on recent work carried out in the Institute. Cod spawn pelagic eggs in late winter meaning they will be affected by increasing surface water temperature more easily. Therefore, concerns exist regarding the increase in sea surface temperature in winter and early spring and 2024 observations have shown that the simulated increase in sea surface temperature of 4 degrees Celsius over the next century has already taken place this year. She highlighted that spawners and the egg stage are critical thermal bottlenecks. Changes in temperature can have long-lasting effects on phenotype, as temperature profoundly influences organismal differentiation during embryonic development by affecting the mitotic cycle rate.

Skjaerven provided a brief insight into cod embryonic development highlighting the similarities among vertebrate embryos at the embryonic stages. However, when increasing the temperature, embryonic gene expression patterns are altered even when the embryos construct fundamental tissue types and organs. Although vertebrate embryos share similarities during early development, these changes in the duration and quantity of gene expression can leave a permanent mark on their phenotype maybe adapted to a warmer climate.

Referring to research on spawning seasons of Atlantic salmon she provided insight into the effects of how water temperature for broodstock in aquaculture changes the nutritional composition in the eggs. Some of the nutrients and metabolites that are altered in the eggs due to broodstock temperature are folate, vitamin B12, vitamin B6 and methionine which are all linked to the 1C metabolism. The 1C metabolism control the remethylation of S-adenosylmethionine needed for DNA methylation which is a sentral mechanism for epigenetic gene regulation. Temperature changes the DNA methylation, controlling the active cell signalling pathways, and affects the weight of the offspring. More research is needed to evaluate the long term effect on growth and robustness of the fish at later stages.

Skjaerven followed up on another study carried out on Atlanitc cod and the impacts of temperature changes on maternal mRNA, some which are defined as maternal effect genes, can be responsible for phenotypic changes in offspring. The speed of embryo development changes depending on temperature. Maternal mRNA is regulated depending on the temperature with certain genes being upregulated and others downregulated months prior to spawning in the ovaries of the mother leaving a change in maternal mRNA in the eggs. "*Temperature during maturation is important for giving instructions to the embryo development*" (Saito et al., 2024) .

T. Saito, M. Espe, M. Mommens, C. Bock, J.M.O Fernandes, and K.H. Skjærven. 2023. Altered spawning seasons of Atlantic salmon broodstock genetically and epigenetically influence cell cycle and lipid-mediated regulations in their offspring. https://doi.org/10.1101/2024.02.03.578741

She concluded that the metabolism interacts with the (epi-)gene regulation adding that broodstock handling affects the nutrient and metabolite status of eggs for example SAM levels which is needed for epigenetic regulation of gene expression. In Alantic cod, temperature (ocean warming) shapes embryonic developmental prospects of the next generation by altering maternal mRNA in offspring, these where regulated months earlier in the ovarian tissue (Skjærven, Maud, Kleppe et al., 2024).

Following an observation from the Moderator regarding the impacts of changes temperature on embryonic development, Skjaerven explained that the short-term incubation changed in warmer water, and embryos after the blastula stage can withstand higher water temperature, probably linked to the embryo being able to adjust the gene expression of zygotic mRNAs.

Sundby stated that cod is a boreal species and that serious impacts can be observed when temperature goes above 10 degrees. Cod strives best between 3 and 10 degrees Celsius and certain compensations are possible. Beyond 10 degrees Celsius this does not seem possible. *"Where is the breaking point?"*

Skjaerven commented that the early embryonic stages are very vulnerable to temperature changes and already challenged by 10 degrees Celsius. However, she pointed out that adaptation by maternal mRNA combined with epigenetic intergenerational changes may be important compensational mechanisms which may be expressed in a different phenotype.

Discussion:

The discussion was based on three guiding questions:

- What is the state of play regarding Celtic Sea cod and the impact of climate change and what are we supposed to expect in the 5 - 10 years to come?
- How could we operationally monitor the effect of climate change on Celtic Sea cod? Are there some ecological/physical reference points that could be developed?
- Is a full recovery of Celtic Sea cod up to the 2005 biomass still possible?

The Moderator thanked all presenters for their informative contributions to the webinar and commented that well-documented trends have been observed over the past years which include some abrupt changes in stock dynamics. He added that it is important to discuss what parameters need to be measured to understand how cod stocks operate, for example monthly temperature changes, phytoplankton cycles etc. He wondered if science knew what indicators would need to be followed up to understand the situation better.

White felt that there was no lack of oceanographic data and that modelling is very defined. The hard part is finding the links between growth/ recruitment and the oceanographic elements. Lab experiments looking at these relationships are very important but transferring any findings to the ocean is far more difficult because of the temporal and spatial nature.

Sundby agreed with White in that temperature information is well available, however, it would be interesting to know where the spawning stock is during maturation times (October – February) and what the temperature is in these areas. In addition, has this affected the spawning areas, i.e. does cod still return to its original spawning grounds or has it moved northwards.

White responded that this information is definitely needed, however, current surveys are being undertaken in Sep – Nov. Only one vessel is carrying out this work though providing only snapshots of information.

Sundby felt that a lot of survey activity is needed to achieve the necessary results and that surveys need to be carried out until February right up to spawning.

The Moderator suggested that current surveys results could possibly be compared and complimented with work carried out on embryonic development to provide additional insight. Skjærvan agreed with this suggestion.

Emiel Brouckaert thanked presenters for the interesting data provided and felt this will provide a good basis for the development of advice by the NWWAC. He commented on the perceived lack of data and referred to opportunities of collecting live data using operational fishing vessels. He wondered if potentially by using AI this missing data could be collected to identify the missing link and referred to the Belgian VIStools project (link).

White responded that "*every fishing opportunity is a sampling opportunity*". Fishing vessels could be used for data gathering. However, he felt that the process of collecting relevant and comparable data is complex. He added that cod is experiencing various bottlenecks during their development and that these bottlenecks may change year to year.

The Moderator commented that the biological response of the stock is one of the most complex aspects of this work. Genetic samples may be needed in order to shed more light on this. He encouraged all scientists to provide available data to the Secretariat in order to improve collaboration processes.

Jochen Depestele agreed that using fishing vessels as a data platform is very useful. However, in his opinion there is already a large amount of scientific research on cod in the Celtic Sea and that the application of FECO could already be evaluated using the information available.

White responded that additional work using Ecopath and Ecosim could help with the development of FECO reference points. Unfortunately, there is no similar work in the Celtic Sea as that of WKIRISH at this point in time.

John Lynch observed that based on anecdotal evidence in the Irish Sea juvenile cod are observed plentiful in static gear, however, they do not seem to mature and show up in surveys. He wondered if this was also an effect of climate change possibly linked to the lack of available food.

Skjaerven commented that looking into the nutrient status of the spawning stock and the embryos could be useful. She referred to deficiencies in B vitamins, for example thiamine, which are needed for metabolism and proliferation of cells.

Sundby stated that juvenile cod have adapted to much higher temperatures than mature cod and do well up to 17 degrees Celsius.

White felt that an observation from one part of the ocean may not translate to another part of the ocean. Ecosystem change and regime shift may be the reason for the difference between the Irish Sea and the Celtic Sea. In 2022 a relatively high recruitment was observed in the Irish Sea which was not followed by an increase in mature individuals, but the reason for this could not be established.

The Moderator mentioned the predation aspect in relation to reduction in stocks wondering if there were new predators on juvenile cod contributing to the mortality. He commented that though the information can be conflicting, the Celtic Sea seems to be at a tipping point depending on which factors are being measured. In terms of management aspects, he felt it would be useful to look at individual aspects and to see what could happen in the short-term. He was wondering if changes are going to affect all or only part of the Celtic Sea and what exactly needs to be measured in the short-term.

White wondered why the 2005 biomass was set as a reference point in this questions and what aspects can actually be managed. Climate change, increase in temperature, cod's physiological response cannot be managed, only fishing pressure management can be adjusted. And if this is not the primary driver than only more data can be gathered. He felt this was a society wide discussion to see how the ecosystem function can be maintained in the light of food production impacted by climate change.

The Moderator agreed that the management and political dimensions need to be integrated in the discussion. He explained that recovery to the 2005 biomass level influences the ICES advice. Moreover, from a political point of view, the Western Waters Multiannual Plan states that when the stock goes below the biomass limit reference point, additional effort is needed, e.g. technical measures, quota restrictions and a bycatch TAC. In this regard, there are EU-UK discussions ongoing on new technical measures for the Celtic Sea which could include seasonal closures. However, there is also a legal requirement in relation to aspects of proportionality. At the moment cod is under 1% of catches in the Celtic Sea and it is important to identify if this recovery can still be achieved. It seems to be more of a political decision regarding the objectives of this work.

Gregory Casey wondered if the role of seismic surveys in the Irish Sea and Celtic Sea and particularly off the south coast of Ireland has been considered as numerous surveys have been carried out in this area over the past ten years. He added that there was no regulation in Irish waters regarding these surveys.

The Moderator felt that all ICES advice is informed by the oceanographic surveys carried out for example by the Marine Institute and Ifremer.

White added that in relation to geophysical surveys and concerns regarding the sound energy effects specifically on young fish, very few surveys have been carried out. He felt that most of these surveys are likely to be carried out outside spawning periods when the weather is better.

Sundby commented that in the Norwegian sector of the North Sea a large study has been carried out on these issues looking at how to prevent impacts of seismic studies in spawning areas. He felt it was not easy to avoid carrying out these surveys during spawning season as fish spawn at different times. Concerns exist and impacts on gadoids are trying to be avoided.

Le Barzic wondered if there was a study on how robust the current assessment model is with fewer data available for inclusion on cod.

The Moderator referred to the last benchmark using the mean weight in 2015 which unfortunately has led to overestimates of future recruitment.

White explained that a retrospective analysis is included in the ICES for assessments as well as forecasts to see how well the assessment holds together. He felt that the cod assessment is quite robust. A "leave one out" assessment is also being carried out where a data series is left out of the assessment, for example the commercial index or the age. However, the fewer information points are included in the model, uncertainty, i.e. confidence intervals, increases. While the spawning stock intervals in the current assessment are quite tight, fishing pressure starts to widen up at the end of the time series due to uncertainty.

The Moderator felt that further action is needed by the AC on this topic and referred to scientific diagnostics wondering if ICES answers to questions posed by managers. He felt that due to the workload it was impossible to carry out another benchmark so soon after the last one. He was convinced that a synthesis of all this work would be beneficial possibly via an ICES symposium.

Lundby suggested that comparative studies of cod ecosystems which are in a similar situation as the Celtic Sea would be good to carry out and that ICES could take the responsibility to coordinate these studies. He referred to the border on the US coast, the Georges bank cod stock, though the thermal conditions are dissimilar to the Celtic Sea. He felt though that the southern part of the North Sea could be compared to the Celtic Sea. He also referred to the local cod stocks in the Skagerrak which seems to have similar thermal conditions as in the southernmost part of the North Sea and the Celtic Sea. A comparative study could provide more insight here.

White responded that any scientist can propose a themed sessions for the ICES annual science conference which may be a good starting point for follow up work on this topic. Commenting on the benchmark, he felt that there was currently no credible new information that would lead to a drastic change in the advice. He added that a much longer-term forecasting method seems to be what is needed, linked with an ecosystem approach which would be best carried out via a PhD study or postdoc work which needs additional funding.

The Moderator felt that the collapse of recruitment over the past few years seems to be the most critical aspect. He agreed that not all work can be carried out by ICES.

Next Steps

The Moderator thanked everyone for their contributions to this webinar. He concluded that with the many works presented, a clearer picture could emerge, but also new questions may emerge.

He added that if there are new requests by scientists regarding sampling for cod, they could send these to the Secretariat who could circulate these to members.

He felt that the AC needed some time to digest all the information, but that this may just have been the first of a series of workshops on this topic.

Close

Matilde Vallerani added that this webinar was timely just ahead of the presentation of the ICES advice at the upcoming NWWAC meetings in Ghent. This should lead to the production to relevant advice to the Commission in support of their discussions at the Specialised Committee on fisheries.

The Moderator closed the meeting adding that a meeting report will be circulated in due course and that presentations will be made available online.

Participants

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